WIDEBAND FREQUENCY CHARACTERIZATION OF A SHAPE MEMORY POLYMER

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ABSTRACT

This study is an experimental evaluation of the mechanical properties of shape memory polymer Veriflex® under different tests conditions. Veriflex® was chosen because of its easy accessibility and its properties similar to epoxy resins which make it very suitable for use in a wide variety of technical applications. Dynamic mechanical analysis (DMA) has been used to determine the evolution of the viscoelastic properties versus temperature and frequency under harmonic loading. The time-temperature superposition principle has been found to be valid for this material. This is illustrated here through the use of the master curves. Furthermore a modal analysis on a Veriflex® rectangular plate has been performed in order to reach higher frequencies than the DMA, and a finite element model was employed to find the viscoelastic properties of the material. A correlation between these two experimental methods allowed to highlight a disparity of results explained by the deterioration of the Veriflex® over time.

1 INTRODUCTION

Shape memory polymers (SMP) have the capability of changing their shape in response to an external stimulus [1]. The glass transition temperature Tg, is the reference point where the higher temperature component starts to melt. When the SMP is heated above Tg, it is soft and rubbery and it is easy to change its shape. When subsequently cooled below Tg, it retains the given shape (shape fixing characteristic). When heated again above Tg, the material autonomously returns to the original permanent shape [2]. The shape-memory effect is in principle a behavior inherent to all polymers. However, polymers that exhibit a useful shape-memory effect must demonstrate a sharp transition temperature and a rubbery plateau, along with relatively large strain capacity without local material damage [3]. Only a few polymers that satisfy these criteria are described in the literature [4]. The characterization of these materials is necessary over a wide frequency band for their current and future applications [5]. For this, a dynamic mechanical analysis and a modal analysis have been performed in order to determine as well as possible a law of time-temperature equivalence [6].

2 DYNAMIC MECHANICAL ANALYSIS

Dynamic mechanical analysis (DMA) of Veriflex® has been performed using BOSE Electro Force equipment. The Veriflex® sample is tested from 0.01 Hz to 10 Hz (from static to dynamic), a sinusoidal force is applied, while viscoelastic properties (storage modulus E', loss modulus E'' and loss factor $tan\ \delta$) are measured every 2°C in isothermal conditions between 25°C and 90°C. Veriflex® shows huge loss of storage modulus while the temperature is increasing, from about 1000 MPa at 25°C to 1 MPa at 90°C. Curves of E' vs. frequency at one temperature (Figure 2) can be shifted to overlap with adjacent curves (Figure 1). The time superposition shift factor a used for E' must be the same for $tan\ \delta$ to get a time-temperature equivalence. In our case, the shift factors a are obtained through an optimisation procedure, and are equivalent for both E' and $tan\ \delta$, in coherence with the time-temperature equivalence. The master curve of the storage modulus is given in Figure 1.

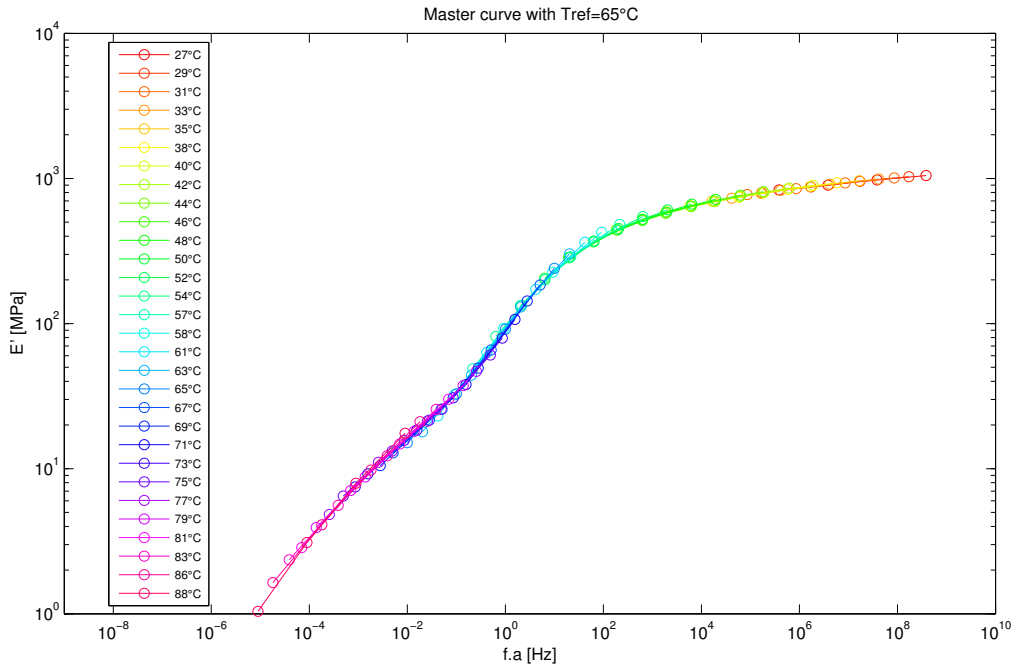

Figure 1. Veriflex® master curve for the storage modulus (E')

3 MODAL ANALYSIS

A modal analysis on a Veriflex® rectangular plate has been performed in free-free conditions, with a temperature control between 20°C and 50°C every 10°C. Contactless actuators and sensors have been used to avoid undesirable effects on the structural behaviour. Experimental modal analysis allowed to obtain modal frequencies (ten frequencies are identified between 100 Hz and 700 Hz), modal damping and mode shapes. At the same time, a finite element model of this plate was established with the same conditions as in experimental (free-free conditions, elastic homogeneous) and a presumed Young's modulus. Numerical modal analysis gives modal frequencies and mode shapes, and mechanical parameters are obtained through the use of model-test correlation and model updating. Just as dynamical mechanic analysis, the obtained Young's modulus of Veriflex® (taken for the storage modulus) depends on the temperature and the frequency as shown in Figure 2.

4 CORRELATION BETWEEN DMA AND MODAL ANALYSIS

This study intends to compare the results obtained with the DMA and those collected by the modal analysis. In both cases, according to the time-temperature equivalence detected by the DMA, the storage modulus should be the same. However the storage modulus for the modal analysis is around 2000 MPa contrary to only 1000 MPa for the DMA at the same temperature, this is a huge gap between these two experimental methods (Figure 2). The possible explanation is that these tests were performed with a time lag of two years. Specifically, Veriflex® samples were elaborated and tested on the DMA in the same year, while the modal tests were performed on these same samples two years later.

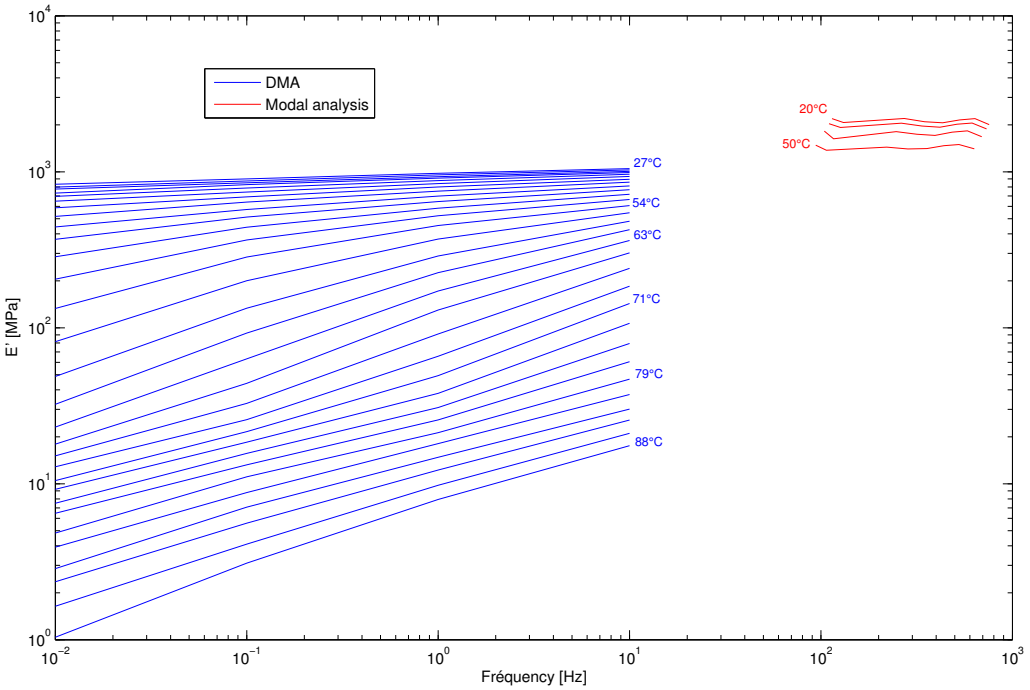

Figure 2. Correlation plot between DMA (blue) and modal analysis (red)

5 CONCLUSION

The objective of this study was to highlight the time-temperature equivalence by comparing two experimental methods allowing the identification of the storage modulus over frequency and temperature. This equivalence has been checked on a sample tested at a given moment with the DMA. However, the deterioration over time of the Veriflex® was not foreseen. Thus, the modal analysis, which has been performed at a later time, could not conclude on the validity of this equivalence over a wide frequency band. Indeed, the material stiffness increased, the Veriflex® storage modulus doubled over two years. Further investigations are needed to clarify the Veriflex® behaved. The age of the material should be taken into account by conducting a series of test runs at the same year. The correlation between DMA and modal analysis remains to be carried out.

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